Mon. Not. R. Astron. Soc. **000**, 1–7 (1999)

On the lithium abundance dispersion in late-type Pleiades stars

R. D. Jeffries
Department of Physics, Keele University, Keele, Staffordshire, ST5 5BG, UK

Received 18 March 1998

ABSTRACT
I present the results of a programme to monitor the strengths of the Li I 6708Å, K I 7699Å and chromospheric Hα lines in a group of cool Pleiades stars. Consistent instrumentation and analysis techniques are used to show that there is no Li I variability on timescales of 1 year that could possibly account for the apparent spread in Li abundances seen in Pleiades stars between effective temperatures of 4800-5200 K. Comparison with published data reveals tentative evidence for variability on 10 year timescales, but at a very low level. The lack of chromospheric activity variability above levels of 20 to 30 percent makes it difficult however, to rule out evenly distributed magnetic activity regions causing a scatter in the Li I line strengths at a given abundance. The similar star to star scatter of K I line strengths in these and published data reinforces the conclusion that it is still unsafe to attribute the Li I line strength dispersion to a large variation in Li depletion at a given mass.

Key words: stars: stars: abundances – stars: late-type – stars: interiors – open clusters and associations: individual: Pleiades

1 INTRODUCTION

Lithium is unique among metals – it is produced in the big bang, but is destroyed by p,α reactions at low temperatures ($\sim 2.4 \times 10^6$ K) in stellar interiors. Observing Li in the cool stars of young open clusters is an excellent way of exploring and calibrating the physics of internal stellar mixing due to convection or additional "non-standard" processes. Rapid angular momentum loss as stars reach the ZAMS may make Li depletion due to poorly understood mechanisms such as rotational mixing, much more dramatic. Such investigations are important in understanding stellar physics, but also in deciding whether present day Population II Li abundances have hardly changed from the primordial big bang nucleosynthesis value. This is supported by "standard" models that feature *only* convective mixing (Deliyannis, Demarque & Kawaler 1990, Bonifacio & Molaro 1997), but other models including "non-standard mixing" predict that the Population II Li has been depleted from primordial values a factor of 2-3 higher (Deliyannis & Ryan 1997, Pinsonneault et al. 1998).

A particular problem for the standard models that has emerged in the last 15 years is the observation that cool stars (4500 K< T_{eff} <5400 K) in the Pleiades (age 100 Myr) and Alpha Per (age 50 Myr) clusters exhibit an apparent Li abundance spread of more than an order of magnitude at a given mass (Duncan & Jones 1983, Butler et al. 1987, Soderblom et al. 1993a [hereafter - S93a], Balachandran, Lambert & Stauffer 1996, Randich et al. 1998). This spread cannot be reconciled with standard models, which predict a unique amount of pre-main sequence (PMS) Li depletion at a given mass and age.

Several explanations have been put forward which assume that the observed spread corresponds to a *real* dispersion in the Li abundances. These have been guided by the correlation (albeit an imperfect one) of reduced Li depletion and rapid rotation (S93a, Martín 1997, Randich et al. 1998). Extra mixing as stars spin down towards the ZAMS is one possibility (Chaboyer et al. 1995). The observed spread in rotation rates at the ZAMS could lead to different efficiencies for rotationally induced mixing. Unfortunately, even the most recent models, which incorporate early angular momentum loss via a circumstellar disk, seem unable to explain the size of the abundance dispersion (Pinsonneault et al. 1998). Others have postulated that structural changes associated with rapid rotation (Martín & Claret 1996) or dynamo induced magnetic fields in the convection zone (Ventura et al. 1998) might reduce the efficiency of standard PMS Li depletion in rapid rotators. Other combinations of mechanisms have been plausibly suggested, such as mixing by internal gravity waves plus the magnetic blocking of mechanical flux through the bottom of the convective zone in rapid rotators (Schatzman 1993, Montalbán & Schatzman 1996). These ideas seem promising because the observed Li depletion is significantly less than the conservative predictions due to standard PMS convective mixing alone (Jeffries & James 1999).

Another school of thought is that the *apparent* Li abundance dispersion might largely be explained in terms of a scatter in the equivalent width (EW) of the Li I 6708Å line (almost exclusively used for this work) at a given Li abundance – caused by NLTE, chromospheres, or large-scale photospheric inhomogeneities such as plages or starspots. It has long been known that the reduced temperature in sunspots increases the observed EW of the Li I 6708Å line (Giampapa 1984). Young, cool stars are known to have much larger photospheric inhomogeneities than the Sun, which are associated with their enormous magnetic activity. The most recent modelling work (Carlsson et al. 1994, Houdebine & Doyle 1995, Stuik, Bruls & Rutten 1997) indicates that these effects may indeed induce a scatter in the apparent Li abundances if, as is normally the case, homogeneous, one dimensional atmospheres and $T_{\rm eff}$-colour relationships are used to convert observed EWs into abundances. Impetus has been given to these explanations by two pieces of observational work. S93a (see also Stuik et al. 1997) find that the K I 7699Å line, formed in similar conditions to the Li I line, also shows a rotation-dependent EW scatter (albeit smaller than that exhibited by Li I) at a given colour. As no potassium abundance variations are expected in the Pleiades, this result challenges our understanding of how neutral alkali lines are formed in cool stellar atmospheres. Russell (1996) examined the subordinate line of Li I at 6104Å in several late-type Pleiads. He argued that Li abundances from this line are lower and show considerably less scatter than from the Li I 6708Å line, possibly because of different sensitivities to NLTE conditions and chromospheric activity. Russell's conclusions have since been challenged because of the difficulty in deblending the weak 6104Å line from stronger nearby lines (Martín 1997).

A useful test of whether Li abundance variations are real is to search for variability in the Li I 6708Å EW. If the scatter in Li abundances is caused by large-scale atmospheric inhomogeneities one might expect to see EW variations associated either with magnetic activity cycles or with the rotational modulation of spots and plages. Spots are often demonstrably asymmetric in their surface distribution on young, active stars, which for instance, allows rotation periods to be measured from light curve modulations (O'Dell & Collier-Cameron 1993). The search for Li EW variability has a chequered history and is reviewed by Fekel (1996). There are individual examples of young active field stars where EW variations on timescales of the rotation period have been reported (*e.g.* Robinson, Thompson & Innis 1986, Basri, Martín & Bertout 1991, Patterer et al. 1993, Jeffries et al. 1994, Eibe et al. 1999) and other studies which claim to detect no variations at the 5% level or less (*e.g.* Boesgaard 1991, Pallavicini et al. 1993). The only study carried out so far in young clusters is that of S93a. They say that observations of some cool Pleiades stars taken on several occasions show no EW variations beyond their estimated errors of ∼20 mÅ, but no details are given. As the Li I 6708Å EWs in late-G and early-K type Pleiads range from ∼100 mÅ to ∼300 mÅ this amount of variability would seem unable to account for any significant fraction of the apparent Li abundance dispersion.

To put this important result on a firmer footing, I have begun a programme to monitor the Li I 6708Å line in a selection of late-G and early-K type Pleiads over long timescales; to test for variability, to see whether any variability is also present in the K I 7699Å line and to see whether any variability is correlated with changes in chromospheric activity. In this short paper I present the first results of this programme which allow a precise investigation of variability on 1 year timescales using data taken with identical instrumentation and on ∼10 year timescales for the first time, by comparison with the results of S93a.

2 OBSERVATIONS AND ANALYSIS

2.1 Target selection

A dozen Pleiades stars were selected for re-observation from Table 1 in S93a. They were chosen to have 4800 $< T_{\rm eff} <$ 5200 K, based upon the colour-$T_{\rm eff}$ relation used by S93a in their analysis, were not known spectroscopic binaries and had a large range of projected equatorial velocities ($v_e \sin i$) and Li I 6708Å EWs.

2.2 Spectroscopy

The spectroscopy was performed at the 2.5-m Isaac Newton Telescope (INT) on the nights of 1997 November 10 and 1998 November 26. In both cases precisely the same instrumental set up was used. The Intermediate Dispersion Spectrograph, 500 mm camera, H1800V grating and a TEK 1024 pixel square detector were used to cover the spectral region from 6510Å to 6755Å at a dispersion of 0.23Å per 24 μm pixel. A 1 arcsec slit projected to just over 2 pixels on the CCD, giving an instrumental spectral resolution (confirmed by arc lines) of 0.48Å. A second wavelength setting was also used that covered the range 7570Å to 7790Å at 0.22Å per pixel and an instrumental resolution of 0.46Å.

The usual calibration bias frames, tungsten flat fields and B star spectra were taken, as well as copper/neon lamp exposures at every target position. A set of "minimum chromospheric activity" standard stars, from the list in Soderblom et al. (1993b), were also observed at high signal to noise (S/N). The data were reduced and spectra extracted and wavelength calibrated using the Starlink FIGARO software package. Two exposures of each Pleiades target were taken at each wavelength setting. The exposure times were judged to yield S/N levels of 80-110 per pixel in the continuum of the co-added Li I 6708Å spectra and 55-70 per pixel in the continuum of the co-added K I 7699Å spectra.

The seeing was not particularly good on either night (1.5-2.5 arcsec) and the final 4 hours of the 1997 observations were badly cloud affected. Nevertheless I was able to complete observations of six of the programme targets in 1997 and nine in 1998. A log of the observations and the S/N levels achieved in each co-added spectrum is given in Table 1.

EWs of the Li I 6708Å, Ca I 6718Å and K I 7699Å lines were measured by direct integration below continuum levels which were determined from polynomial fits to approximately line free regions of the spectra. For targets where

Table 1. A log of the INT spectroscopic observations and EW measurements.

Name	$(B-V)_0$	$v_e \sin i$	Date	UT		$\lambda\lambda 6510-6755$				$\lambda\lambda 7570-7790$
					S/N	Li I6708Å	Ca I6718Å	Excess Hα	S/N	K I7699Å
		km s^{-1}				EW (mÅ)	EW (mÅ)	EW (mÅ)		EW (mÅ)
Hz 34	0.89	<7	10 Nov 1997	20:30	90	154 ± 7	186 ± 6	158 ± 12	60	261 ± 13
Hz 345	0.81	18	10 Nov 1997	21:00	80	282 ± 10	176 ± 7	1508 ± 15	60	336 ± 12
Hz 174	0.81	28	10 Nov 1997	21:30	90	299 ± 12	220 ± 14	1770 ± 30	60	391 ± 24
Hz 916	0.83	<7	10 Nov 1997	22:15	95	187 ± 9	180 ± 7	217 ± 15	60	282 ± 11
Hz 2407	0.91	<7	10 Nov 1997	23:00	100	116 ± 7	218 ± 6	340 ± 9	65	317 ± 12
Hz 2034	0.93	75	11 Nov 1997	00:00	85	220 ± 13	238 ± 14	1060 ± 50	70	469 ± 16
Hz 345	0.81	18	26 Nov 1998	20:30	100	270 ± 5	172 ± 6	1250 ± 15	60	337 ± 15
Hz 174	0.81	28	26 Nov 1998	21:00	90	290 ± 11	203 ± 14	1750 ± 50	55	433 ± 32
Hz 916	0.83	<7	26 Nov 1998	22:00	110	185 ± 4	169 ± 6	207 ± 12	60	261 ± 15
Hz 2407	0.91	<7	26 Nov 1998	23:00	95	125 ± 5	210 ± 8	351 ± 9	55	324 ± 16
Hz 2034	0.93	75	27 Nov 1998	00:00	80	230 ± 19	253 ± 13	1490 ± 80	60	452 ± 20
Hz 34	0.89	<7	27 Nov 1998	01:30	110	146 ± 5	191 ± 5	169 ± 10	60	277 ± 10
Hz 263	0.84	10	27 Nov 1998	02:40	100	240 ± 5	166 ± 6	359 ± 11	65	300 ± 10
Hz 1095	0.86	<7	27 Nov 1998	03:30	90	130 ± 6	187 ± 9	180 ± 13	55	285 ± 15
Hz 1124	0.91	7.5	27 Nov 1998	04:30	90	189 ± 7	253 ± 9	527 ± 15	60	335 ± 12

I have a pair of observations from 1997 and 1998, I was careful to use *identical* continuum regions, after correcting the spectra to a similar rest velocity, so that EW measurements are directly comparable for these stars. Note that it was not possible to select identical continuum regions for all the targets because the rapid rotators suffer from extensive blending and consequent blanketing of the continuum. The K I line is affected by a small amount of telluric absorption. This was corrected for by reference to a B-star spectrum.

I also measured the Hα feature as an estimator of chromospheric activity. This is usually in absorption in inactive stars, but can be filled in or even show emission in the most active G/K stars. Again, consistent continuum measurements were used in pairs of observations to aid comparison. Following Soderblom et al. (1993b), I subtracted the spectrum of each Pleiades star from the spectrum of a normalised minimum activity star of similar intrinsic colour. The standards used are the same as those in Soderblom et al. (1993b), namely, HD 3651, HD 4256, HD 4628, HD 10476, HD 166620 and HD 182488. For the two stars with $v_e \sin i > 20\,\mathrm{km\,s^{-1}}$, the standard star was broadened to the appropriate $v_e \sin i$, before subtraction. The excess EW of the resultant "emission line" can be taken as a measure of the chromospheric activity and is comparable with the measurements in Soderblom et al. (1993b). Again, telluric features were visible in some of the spectra and were removed by reference to a scaled high S/N spectrum of a rapidly rotating B-star.

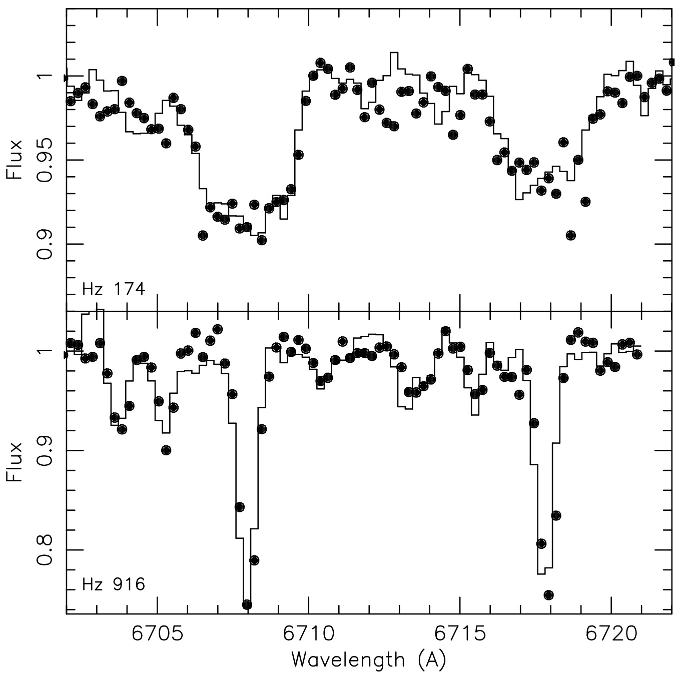

Figure 1. Spectra for Hz 174 and Hz 916 around the Li I 6708Å line from 1997 (dots) and 1998 (solid lines).

3 RESULTS

The EW measurements for all the relevant lines are given in Table 1, along with the S/N in the co-added spectra.

Table 2. A comparison of deblended Li I 6708Å EWs from this paper and Soderblom et al. (1993a).

Name	Deblended Li I EW (mÅ) S93a	Nov 1997	Nov 1998
Hz 34	134 ± 18	139 ± 7	131 ± 5
Hz 174	241 ± 25	286 ± 12	277 ± 11
Hz 263	290 ± 12	–	226 ± 5
Hz 345	245 ± 12	269 ± 10	257 ± 5
Hz 916	199 ± 12	173 ± 9	171 ± 4
Hz 1095	138 ± 12	–	116 ± 6
Hz 1124	217 ± 18	–	174 ± 7
Hz 2034	222 ± 36	204 ± 13	214 ± 19
Hz 2407	125 ± 12	101 ± 7	110 ± 5

Table 3. A comparison of Ca I 6718Å EWs from this paper and Soderblom et al. (1993a).

Name	Ca I EW (mÅ) S93a	Nov 1997	Nov 1998
Hz 34	186 ± 18	186 ± 8	191 ± 5
Hz 174	269 ± 25	220 ± 14	203 ± 14
Hz 263	218 ± 12	–	166 ± 6
Hz 345	182 ± 12	176 ± 7	172 ± 6
Hz 916	203 ± 12	180 ± 7	169 ± 6
Hz 1095	216 ± 12	–	187 ± 9
Hz 1124	237 ± 18	–	253 ± 9
Hz 2034	256 ± 38	238 ± 14	253 ± 13
Hz 2407	229 ± 12	218 ± 6	210 ± 8

Table 4. A comparison of K I 7699Å EWs from this paper and Soderblom et al. (1993a).

Name	K I EW (mÅ) S93a	Nov 1997	Nov 1998
Hz 34	233 ± 18	261 ± 13	277 ± 10
Hz 174	–	391 ± 24	433 ± 32
Hz 263	250 ± 12	–	300 ± 10
Hz 345	321 ± 12	336 ± 12	337 ± 15
Hz 916	222 ± 12	282 ± 11	261 ± 15
Hz 1095	235 ± 12	–	285 ± 15
Hz 1124	369 ± 18	–	335 ± 12
Hz 2034	–	469 ± 16	452 ± 20
Hz 2407	294 ± 12	317 ± 12	324 ± 16

Table 5. A comparison of *excess* Hα EWs from this paper and Soderblom et al. (1993b). Where several measurements were given by Soderblom et al. (1993b), all are listed.

Name	Excess Hα EW (mÅ) S93b	Nov 1997	Nov 1998
Hz 34	230 ± 15	158 ± 12	169 ± 10
Hz 174	–	1770 ± 30	1750 ± 50
Hz 263	480 ± 15	–	359 ± 11
	340 ± 15		
	390 ± 15		
Hz 345	1570 ± 15	1508 ± 15	1250 ± 15
	1050 ± 15		
	1240 ± 15		
Hz 916	280 ± 15	217 ± 15	207 ± 12
	290 ± 15		
Hz 1095	140 ± 15	–	180 ± 13
	340 ± 15		
Hz 1124	580 ± 15	–	527 ± 15
Hz 2034	–	1060 ± 50	1490 ± 80
Hz 2407	230 ± 15	340 ± 9	351 ± 9

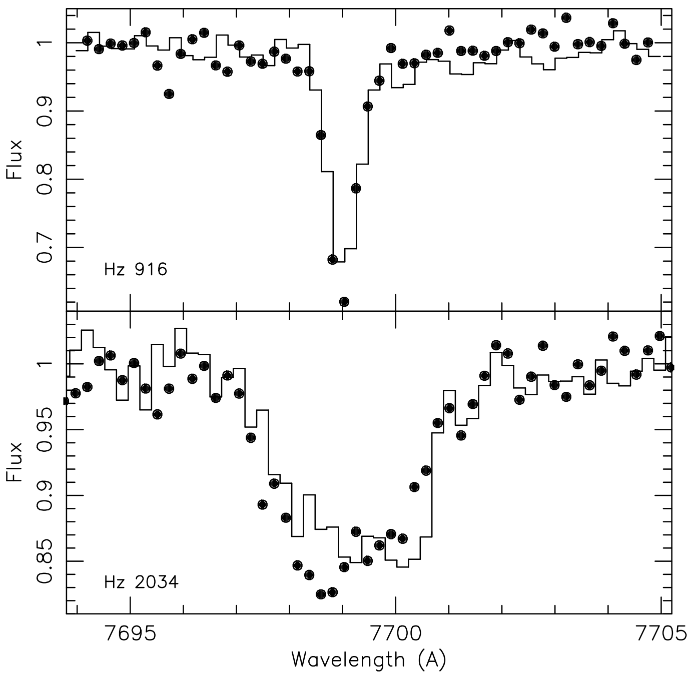

Figure 2. Spectra for Hz 916 and Hz 2034 around the K I 7699Å line from 1997 (dots) and 1998 (solid lines).

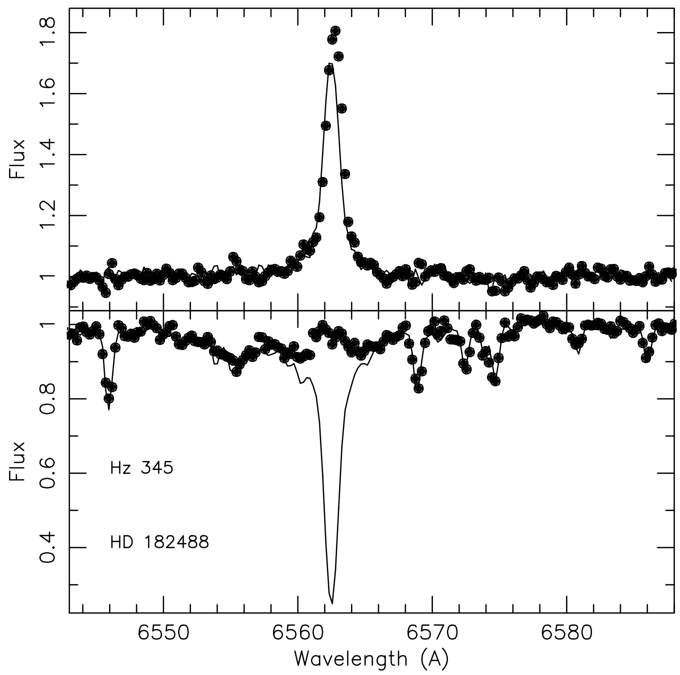

Figure 3. The bottom panel shows the spectral subtraction technique applied to Hz 345 (dots) around the Hα line in 1998. The template star (solid line) is HD 182488. The top panel shows the subtracted "excess" Hα emission lines for Hz 345 in 1997 (dots) and 1998 (solid line).

Tables 2-5 list these results again and compare them with the results of S93a and Soderblom et al. (1993b). In Table 2 I compare the "deblended" Li I 6708Å EWs quoted by S93a. The blend in question is with a weak Fe I feature at 6707.44Å, which has a strength of $20(B-V)_0 - 3\,$mÅ according to S93a. The EWs listed in Table 2 have all been corrected according to this formula. Figures 1 and 2 show examples of the spectra from 1997 and 1998 for comparison of the Li I, Ca I and K I lines. Figure 3 illustrates the spectral subtraction technique used for Hα and shows an example of the comparison between excess Hα emission in 1997 and 1998.

3.1 Variability on one year timescales

The strength of the small dataset presented here is that the observations were taken with identical instrumentation and reduced in a very consistent manner. Comparison of the six Pleiades stars in common to the November 1997 and November 1998 datasets allows a strong statement on the amount of variability on yearly timescales, independent of any possible systematic errors in the EW measurements. It is clear from Tables 2-4 that the EWs of the Li I Ca I and K I lines are completely in agreement. For Li I the biggest (and most significant) discrepancy is $(12\pm11)\,$mÅ for Hz 345. The weighted mean discrepancy for all six stars is $(2\pm4)\,$mÅ, with an rms discrepancy of less than 14 mÅ at a 95 percent confidence level.

The EW discrepancies can be somewhat larger for the other two lines, although their errors are larger and the significance of the discrepancy is still less than 1.5σ in all cases. From the excess Hα EWs, there is clear evidence for variability in the chromospheric emission of Hz 345 and Hz 2034 at the 20-30 percent level, whereas the other four stars are constant to better than 10 percent.

3.2 Variability on ten year timescales

The dataset provided by S93a allows variability on longer timescales to be probed. Here we have a slightly larger dataset (nine stars), but there could be systematic differences in the EW measurements due to choice of continuum placement and slightly different spectral resolutions. Ignoring these possible systematic errors for the present, we can see that the 1997/98 Li I line measurements are remarkably consistent with those of S93a taken in 1988 and 1990. The maximum and most significant discrepancy is $(64\pm13)\,$mÅ for Hz 263. The weighted mean discrepancy between S93a and our 1998 observations is $(21\pm5)\,$mÅ, in the sense that the S93a EWs are larger. However, from the error estimates, this cannot be explained (is statistically unacceptable) as a *systematic* continuum placement problem and there may be genuine variation in the Li I EWs at an rms level of about 30 mÅ.

A useful check on any systematic error is provided by the nearby Ca I line, which will have been measured with respect to a similar adjacent continuum region. The Ca I line is formed from an excited level and has been shown to be considerably less sensitive to photospheric inhomogeneities than the Li I line. If both the Li I and Ca I line show EW discrepancies in the same sense and of similar size then the continuum placement may be to blame for most of the apparent variation. From Tables 2 and 3, we can see that this may be the case for Hz 263, Hz 916, Hz 1095 and Hz 2407, but Hz 174 and Hz 1124 show Ca I EW discrepancies in the opposite sense to those in Li I. If all the statistical error estimates are correct, then we have to conclude that there is some genuine Li I EW variation at the level of $\sim 30\,$mÅ in at least some Pleiades stars on ~ 10 year timescales.

The evidence for variation in the K I line is also difficult to find. There is some indication that the S93a EWs are systematically lower than those presented here, which make the results for Hz 1124 intriguing. It seems that the EW was larger in the S93a observation, perhaps behaving in a similar fashion to the Li I EW. The other six stars in common, would be quite comparable if I have generally overestimated the continuum level around the K I line by $\sim 3\%$ with respect to S93a. Differences of this order are just plausible because of the many telluric features close to the line, the different resolutions of the observations and perhaps an under-estimation of scattered light in S93a's echelle observations.

Lastly, we can look at chromospheric activity. Soderblom et al. (1993b) list a number of measurements for some stars taken in 1988 and 1990, and our additional measurements paint a consistent picture of low-level variability of less than a factor of two on timescales of 1-10 years. Interestingly, Hz 1124 is the most constant star in our sample (in terms of percentage variation) in contrast to the results from the other lines.

4 DISCUSSION

The new measurements of Li I EW presented here were obtained with identical instrumentation and taking care to avoid any systematic errors. The conclusion drawn from a small sample is that the Li I EW is not variable on one year timescales at more than a level of about 10-15 mÅ. For a late G/early K star with an effective temperature of 5000 K the curves of growth presented in S93a can be used to estimate that this would produce a spread in Li *abundance* of ≤ 0.1 dex for the most Li abundant stars in the Pleiades and perhaps ≤ 0.15 dex for the least Li abundant Pleiades stars at this temperature. Variations at this level cannot therefore explain the vast majority of the more than one order of magnitude apparent Li abundance scatter in the Pleiades late G/early K stars.

On longer timescales of ~ 10 years, the data do support a limited amount of Li I variability, perhaps as much as an rms of 30 mÅ. While this is still far too small (0.2-0.3 dex) to explain the Li abundance scatter, it does agree with the kind of Li I variations which have been seen on some, but not all, young, nearby, rapidly rotating K-type Pleiades analogues. For example Hussain et al. (1997) measure a 45 mÅ EW variation with rotational phase in AB Dor, and similar variations were recorded by Jeffries et al. (1994) for BD+22° 4409. These variations were interpreted in terms of rotational modulation caused by enhanced Li I from asymmetrically distributed starspots. It is tempting to speculate that the variability seen here is caused by the same phenomenon. However, it is then difficult to understand (other than by appealing to the small sample size) why no variation is seen on yearly timescales. It has been clearly demonstrated (for example by Barnes et al. 1998) that spot patterns on these young stars may only remain coherent for a month or less and in any case, it is unlikely that the stars were viewed at the same rotational phase (rotation periods are too uncertain to check this point). A more likely explanation could lie in magnetic activity cycles. A cycle length of order 11 years (like the Sun) would mean that that any effects of plage or spot activity spread over the whole stellar surface may not show great variation from year to year, but possibly would over the course of many years or decades. There is evidence that some, but not all, cool stars share solar-like magnetic activity cycles (Baliunas et al. 1998). Few stars as active as the Pleiades G/K stars have been studied in such detail, although AB Dor's overall spot coverage does reveal changes on ~ 10 year timescales (Anders, Coates & Thompson 1992).

A more sceptical interpretation is that much of the long term variation is caused by uncertainties in the setting of continuum levels prior to EW measurement. Even continuum level errors at the 1-2 percent level could result in measured EW errors of about 10-20 mÅ. Effects of this size are certainly plausible given the S/N and different spectral resolutions of the datasets. Some support for this explanation is offered by the correlation between Ca I and Li I EW discrepancies in some, but not all, cases. It is therefore still possible that some of the variation is genuine.

The results presented here also suggest that chromospheric activity variations on timescales of 1-10 years are limited to 20-30 percent in these active, young stars. This result is not entirely surprising, although some rare exceptions were found by Soderblom et al. (1993b) in their more extensive Hα survey of the Pleiades. A similar lack of long term variability has been found in the coronal emission of Pleiades stars at X-ray wavelengths (Gagné, Caillault & Stauffer 1995), in contrast to the order of magnitude variability in X-ray activity exhibited by the Sun over the course of its activity cycle. The lack of chromospheric activity variability, combined with the order of magnitude dispersion in the chromospheric activity of the Pleiades stars considered here (presumably due to different rotation rates), make it difficult to argue against active regions distributed over the entire surface being responsible for at least a proportion of the Li I EW scatter. Stuik et al. (1997) have modelled the Li I and K I sensitivity to homogeneously distributed spots and plages on the surfaces of stars similar to those considered here. They find that Li I *and* K I EW scatters of ~ 100 mÅ are possible given the appropriate combinations of spot and plage filling factors.

Stuik et al. (1997) have also shown that the K I line is an extremely good proxy for the Li I line and mimics its response to different atmospheric stratifications. S93a noticed that there was a spread in K I EW at a given $B-V$ and this point has been stressed by Carlsson et al. (1994) and Stuik et al. (1997) as a reason to be sceptical about whether the spread in Li I EW genuinely reflects different Li abundances. The new data presented here confirm this result and also that those stars with the largest Li I and K I EWs tend to be the most chromospherically active and rapidly rotating. Indeed, S93a did not present K I measurements for Hz 174 and Hz 2407 which are among the most rapidly rotating stars of their spectral type in the Pleiades, and have the highest K I EWs in this temperature range. These data reinforce the conclusion that there is a factor of two spread in the K I EW at a given $B-V$ (in the range $0.8 < B-V < 0.95$), compared with a factor of three spread in the Li I EW. While this K I EW scatter remains unexplained, it is dangerous to attribute the spread in Li I EWs to abundance differences. Note though, that at cooler temperatures the spread in Li I EW grows while the K I EW spread remains roughly constant, but the correlation between rotation and Li I EW also becomes much weaker. Perhaps this indicates, in agreement with the predictions of current models (Pinsonneault et al. 1998), that during the PMS phase at least, rotationally dependent non-standard mixing is *not* the architect of spreads in the Li I EW.

5 CONCLUSIONS

I have observed a small sample of Pleiades late G and early K stars with consistent instrumentation and analysis techniques to look for variation in the strength of the Li I 6708Å line on one year timescales. Variability on ten year timescales has also been searched for using previously published data. At the same time I have measured the strength of chromospheric activity and the K I 7699Å line, which might plausibly have shown correlated variations. The following conclusions can be drawn.

(i) The detection of Li I EW variability comparable to the spread in Li I EW in this temperature range would have immediately rejected the hypothesis that the spread reflected a genuine Li abundance scatter. I detect no variability on one year timescales that could correspond to to more than about 0.1 dex in the deduced Li abundances.

(ii) On 10 year timescales there is some evidence for Li I EW variability which could produce 0.2-0.3 dex Li abundance spreads. Because these data were taken with different instruments and spectral resolutions, I remain sceptical about whether such variations are real, due to the difficulty in applying consistent continuum placements.

(iii) The first two conclusions lead us to believe that whatever causes the scatter in Li I EWs, it is not something that varies significantly on 1-10 year timescales.

(iv) There is only 20-30 percent variability in the levels of chromospheric activity in this sample, despite a dispersion in chromospheric activity of an order of magnitude. This makes it difficult to rule out uniformly distributed magnetically active regions as a cause of Li I line strength scatter.

(v) The data reinforce the conclusion that the strengths of *both* the Li I 6708Å and K I 7699Å lines increase with rotation rate and chromospheric activity at a given colour. It seems unsafe to conclude that Li depletion in the effective temperature range 4800-5200 K is correlated with rotation until the large scatter in the K I EWs has been satisfactorily explained.

A number of useful extensions to this work are apparent. Ideally, the sample size should be increased and extended to include cooler Pleiads. It would also be most advantageous to repeat the observations presented here in about 5 years time, using the same instrumentation if possible to avoid systematic errors. Simultaneous photometry or doppler imaging could be used to determine the actual surface coverage of spots or active regions at the time of observation.

Acknowledgements

The Isaac Newton Telescope is operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. RDJ acknowledges the travel and subsistence support of the UK Particle Physics and Astronomy Research Council (PPARC) and the assistance of A. Ford in obtaining the November 1998 dataset. Computational work was performed on the Keele node of the PPARC funded Starlink network.